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Computation of Multimodal Size-Velocity-Temperature Spray Distribution Functions

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Understanding and modeling spray flows is of primary interest in a wide variety of applications including those associated with liquid fuel injectors, industrial coating processes, and agricultural sprays. Probably the most common approach to computing spray flows is the Lagrangian-Eulerian, or particle-tracking method[1]. This method provides an indirect means of solving for the statistical quantities which characterize a spray, by tracking individual particles (or parcels), counting them in specified volumes, and then forming the statistics of interest. Solution of the governing equations does not provide the droplet statistics directly—they result from post-computation averaging of droplet data. While this approach has provided excellent results in many applications, it has some potentially significant drawbacks. Foremost among these is the need to integrate (or simulate) until the statistics of interest are converged. This can lead to prohibitively long computational times.

An alternative approach—one which does not involve simulation or stochastic integration—is to directly compute the evolution of the probability density function (PDF) describing the drops. The purpose of this paper is to continue exploring an alternative method of solving the spray flow problem. The approach is to derive and solve a set of Eulerian moment transport equations for the quantities of interest in the spray, coupled with the appropriate gas-phase (Eulerian) equations. A second purpose is to continue to explore how a maximum-entropy criterion may be used to provide closure for such a moment-based model. The hope is to further develop an Eulerian-Eulerian model that will permit one to solve for detailed droplet statistics directly without the use of stochastic integration or post-averaging of simulations.

This alternative approach, the Maximum Entropy Moment Closure (MEMC) approach, has previously been presented,[2,3] showing that the method is capable of propagating a joint diameter-velocity PDF. This is done by discretizing the diameter axis and deriving sets of velocity moment and expected number density transport equations—one set for each diameter bin. Upon solving these and the gas phase equations, one can reconstruct the joint diameter-velocity PDF which can be integrated to obtain any statistic of interest. Results have shown[2,5] a clear wave-like behavior associated with the spray and have revealed structure within the spray

such as a larger mean diameter at the spray's leading edge due to the effects of drag in the case where the mean injection velocity was greater than the mean gas velocity. These results compare well with the results from a conventional Lagrangian simulation approach.

In the present work, the details of including the random variable of temperature into the phase space and incorporating the effects of energy exchange with the gas phase will be presented. This is an important first step in extending the model for use with non-isothermal sprays. The challenges to be discussed will be how to model the mixed temperature-velocity moments and the energy exchange terms. In addition, the model will be extended to predict multi-modal distribution functions. This is done by solving additional sets of equations representing each mode of the PDF and recombining them into a single PDF. This will ultimately lead to the ability to predict spray distributions in regions of recirculation or intersecting sprays where there may be significant differences in the droplet characteristics. These extensions will be tested on a quasi-one-dimensional model problem and results of expected number density, mean and mean-squared velocity, and mean, mean-squared, and mean-cubed temperature as a function of position and time will be presented for both single- and multi-modal distributions.

References

1. Dukowicz, J. K., "A Particle-Fluid Numerical Model for Liquid Sprays," *J. Comp. Phys.*, vol. 35, pp. 229-253, 1980.

2. Archambault, M. R., "A Maximum Entropy Moment Closure Approach to Modeling the Evolution of Spray Flows," Ph.D. thesis, Stanford University, Stanford, CA, 1999.

3. Archambault, M. R., Edwards C. F., & MacCormack, R. W., "Computation of Spray Dynamics by Moment Transport Equations I: Theory and Development," accepted for publication in *Atomization and Sprays*, 2002.

4. Archambault, M. R., Edwards, C. F., & MacCormack, R. W., "Computation of Spray Dynamics by Moment Transport Equations II: Application to Calculation of a Quasi-One-Dimensional Spray," accepted for publication in *Atomization and Sprays*, 2002.